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THEORETICAL TIME RESOLUTION OF SOUND ENERGY RETURNS FROM A TARG--ETC(U)
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Theoretical Time Resolution of Sound Energy Returns from a Target in the First and Second LORAD Zones

by

Alice Joy-Keith

Preface

This memorandum describes results using a method developed by the author and M. A. Pedersen in work on underwater sound propagation. This memorandum has been prepared because the information herein is believed to be useful in this form to others in NEL and to a few persons or activities outside of NEL. This memorandum should not be construed as a report as its only function is to present for the information of others a small portion of the work which was done on NEL Problem L1-5.

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Method and Results for Target at 100-foot Depth

In connection with a report on underwater sound propagation[1], several studies were made of the relative travel-times required for refracted rays of sound from a 50-foot source to reach a given point receiver. These follow at least four possible paths: (1) up from the source to a reflection at the surface, thence down to the ocean depths and refracted up to be surface-reflected to a receiver; (2) a similar ray of slightly different angle caught by the receiver on its way up, before this second surface-reflection; (3) down from the source to the depths and refracted back to the receiver before, or (4) after, reflection at the surface near the receiver. Other similar groups of four will be mentioned later.

The phase differences of such arrivals were studied over the range of the first zone for a 50-foot source and a 100-foot receiver. This led to a further study, the results of which are presented here in a technical memorandum as being perhaps timely to investigations in signal processing for LORAD and in neighboring fields.

It was assumed that the sound rays above referred to impinge upon, not a receiver, but a small scattering target, located in the first convergence zone, each impingement constituting, then, a new source from which the sound energy would return, by four differ-

1. M. A. Pedersen and Alice Joy-Keith, "Comparison of Experimental and Theoretical Sound Intensities for Convergence Zone Transmission in 3100 fathom Water", NEL Report 738, 1956 (Confidential).

ent paths, to the original source.

One speaks of 4 ray paths. There are, for most ranges, in fact, 8 paths, due to the phenomenon of "caustics". As the inclination angle at which a ray leaves a shallow source increases from that of the ray grazing the lower boundary of the surface channel, the range at which it next appears at the surface decreases at first to a minimum value at the caustic, then increases; so that in general there are at a given range 8 arrivals of sound, from rays which leave the source at 4 smaller and 4 larger angles respectively.

Each of these 8 arrivals striking the target may, then, give rise to 8 rays returning by similar paths to the source, giving in general 64 routes by which sound may make the round trip. In considering the travel-time required for each of these 64 round trips, one finds reciprocal paths with identical travel-times, as A_1C_3 and C_3A_1 in figure 1. There are 28 such pairs. The other 8 paths are unique, as A_1A_1, C_3C_3. Thus there will be 28 + 8 or 36 distinct times of arrival for an echo.

The travel times for each of the 36 possible arrivals back at the source were calculated for the ranges to a target somewhere in the first convergence annulus, i.e., between 32 and 35 miles from the source. The differences in travel-time were found to be of the order of 10 milliseconds or one ten-thousandth of the actual travel-time. So a plot was made, travel-time difference vs range, figure 1, using the travel

times of the fastest ray as datum line and plotting differences from this line.

To consider the relative intensities of these arrivals, reference was made to the intensity vs range plots from the NEL report above cited. The appropriate plot is reproduced here as figure 2.

With these two figures, then, it was possible to determine for any chosen range of target within the first zone what portion of the total energy carried via the 64 routes could be received by a system of any chosen range-resolution. For example, for a system of about 1.6 yards resolution (2-millisecond pulse) the proportions, expressed in db down from the total, are given in column 2 of table 1.

A system of about 16 yards resolution (20-millisecond pulse) can be seen from figure 1 to receive all the energy from a target in the first half of the zone and an amount less than 3 db down from total in the remainder of the zone.

In both of these systems one notes that entries such as those in column 2 of table I represent losses in the two-way propagation. These same losses will appear as decrements in echo-level if target strength remains constant. There are further questions concerning the effect on echo-to-background ratio, but these can not be discussed here because of their great variety.

Procedure for Use of Fugures 1 and 2

The procedure for making these comparisons is as follows: In figure 1, at any chosen range, say 33.25 miles, a group of

lines clustering within a 2-millisec-travel-time interval estimated to have the greatest density (say the group between 15 and 17 ms) is spotted. Each line in this cluster represents a round-trip route for sound following outgoing and incoming paths identified by the letters and subscripts printed at the end of the line, arriving by echo from a 33.25-mile target within a 2-millisecond interval for the whole cluster.

These paths may be identified by their letters A_i, C_i, on the intensity-vs-range chart, figure 2, in which points B_1 to B_4 simply identify caustic ranges and may be disregarded. The intensities as there read, multiplied together, give the intensity of the arrival back at the source. It is then necessary to sum these products, remembering to double all except those where outgoing and incoming routes are the same. The ratio of this sum to the similar sum for <u>all</u> lines crossing this 33.25-mile range, expressed db-wise, is the figure given in column 2 of table I opposite Range 33.25 miles. In these calculations the intensities have been added assuming a random phase relationship. Phase information was retained in part of the original study (1), but it did not materially affect determination of propagation losses.

<u>Results for Target at 1000-ft Depth</u>

An examination of the graphs in the NEL report above cited, from which those of this memorandum are taken, enables one to surmise further conclusions for a shallow source and other depths of target. It can be seen that deepening the target separates the caustics both in range and travel-time difference,

reducing the clustering and also reducing the overlapping totals. As a check on such surmises, results were worked out in full detail for a source at the same fifty-foot depth with a target 1000 feet deep. These results are given in figure 3 and 4 and in table II.

<u>Results for Target in Second Zone</u>

In order to permit limited consideration of zones of higher order, the shallow target case has been studied for the second zone. Results drawn from figures 5 and 6, are presented in tables III and IV. Terminations when shown for plotted relative travel-times and intensities in all figures are at the geometric range limits of the rays. Other range limits beyond borders of drawings are indicated by arrows. The presence of only a single ray in a certain range interval indicates two-way spherical divergence.

<u>Conclusions</u>

Considering a 50-foot E/R transducer and a small scattering target in the first or second LORAD zone, the effect of resolution varies in such a way as can best be noted by dividing the zone into thirds. In the third of the zone nearest the source the effect of resolution is negligible. In the middle third the additional propagation loss due to resolution rises to a maximum. In the outer third of the zone, this effect decreases as the convergence decreases. The greatest increase in propagation loss due to resolution in either zone will be 8 or 9 db for 100-foot depth of target and 1.6-yards resolution. It will be about half that much for either a 1000-foot target depth or for a 16-yard resolution at 100 foot depth.

All calculations in this memorandum have neglected possible increases in zone width caused by surface channeling.

TABLE I

Signal strength to be expected with sonar of 1.6 yds
(2-millisecond) Resolution

Source 50 feet deep, target 100 feet deep in first convergence zone

Range to Target (Nau. mi)	Energy Received to Total Energy (Ratio, db.)	Descriptive Remarks
32.08	0	At first caustic
32.30	0	Between caustics
32.36	-0.3	At Second caustic
32.50	-1.5	Betw en caustics
32.62	-1.2	At third caustic
32.75	-2.5	Between caustics
32.85	-2.2	At fourth caustic
32.92	-4.4	
32.95	-3.4	
33.12	-4.0	
33.16	-3.9	At first drop-out
33.25	-6.1	
33.54	-7.0	
34.40	-8.3	
34.70	0	Only one arrival remaining
35.51		End of zone.

TABLE II

Signal strength to be expected with sonar of 1.6 yds (2-millisecond) resolution

Source 50 feet deep, target 1000 feet deep in first LORAD convergence zone

Range to target (Nau. mi.)	Energy received to total energy (Ratio, db down)	Descriptive remarks
31.02	0	At first caustic
31.05	0	Between caustics
31.41-	0	At second caustic, omitting it
31.41+	-0.3	At second caustic, including it
31.50	-1.66	Between caustics
31.63	-3.05	As route A_1 drops out
32.00	-3.20	Between caustics
32.26	-3.02	As route A_2 drops out
33.00	-3.01	Between caustics
33.57-	-2.99	At third caustic, omitting it
33.57+	-1.18	At third caustic, including it
33.74-	-2.50	As route C_1 drops out, including it
33.74+	-1.37	As route C_1 drops out, omitting it
33.78-	-1.51	At fourth caustic, omitting it
33.78+	-0.96	At fourth caustic, including it
33.84-	-2.65	As route C_2 drops out, including it
33.84+	-2.03	As route C_2 drops out, omitting it
34.00	-3.14	After last caustic
34.50	-4.33	After last caustic
35.26-	-3.58	As route C_3 drops out, including it
35.26+	-2.94	As route C_3 drops out, omitting it
35.35-	-2.73	As route C_4 drops out, including it
35.35+	-2.05	As route C_4 drops out, omitting it
36.00	-0.84	Only four routes remaining, one predominant
36.42-	-1.20	As A_3 drops out
36.42+	0	One route only remaining, to
37.30		End of zone

TABLE III

Signal strength to be expected with sonar of 1.6 yds (2-millisecond) resolution

Source 50 feet deep, target 100 feet deep in second convergence zone

Range to target (Nau. mi.)	Energy received to total energy (Ratio, db)	Descriptive Remarks
64.60	0	At first caustic
64.85	-0.5	At second caustic
65.10	-1.6	At third caustic
65.35	-3.1	At fourth caustic
65.50	-4.4	Before dropouts begin
66.00	-4.0	After first dropout
67.35	-6.0	After second dropout
68.15	-8.8	Approximately steady at this value until
69.15	-8.8	Fifth dropout, then loss decrease as number of possible routes diminishes to one at
69.85	0	End of zone.

TABLE IV

Signal strength to be expected with sonar of 16 yards (20-millisecond) Resolution

Source 50 feet deep, target 100 feet deep in second convergence zone

Range to target (Nau. mi)	Energy received to total energy (Ratio, db)	Descriptive Remarks
64.60	0	At first caustic
64.85	0	At second caustic
65.10	0	At third caustic
65.35	0	At fourth caustic
66.15	0	Before dropouts begin
66.70	-0.6	" " "
67.00	-1.2	" " "
67.15	-1.8	" " "
67.60	-2.4	After first dropout
68.00	-4.7	Approximately steady at this value until
68.95		Third dropout, then loss decreases as number of possible routes diminishes to one at
69.85	0	End of zone.

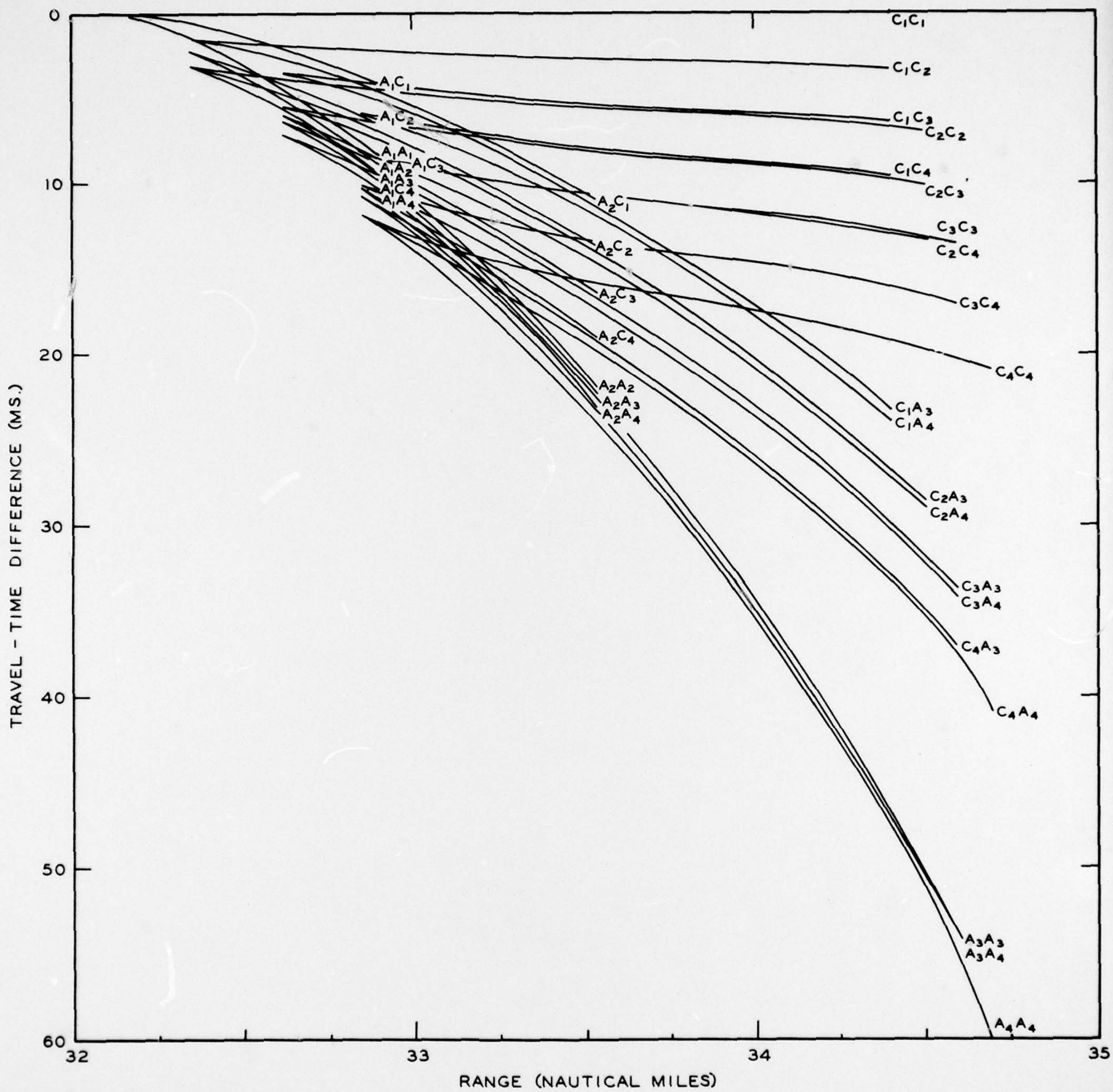

Fig. 1. Round-trip travel-time differences in milliseconds vs range in nautical miles for sound energy from a source 50 feet deep to and from a target 100 feet deep in the first LORAD zone.

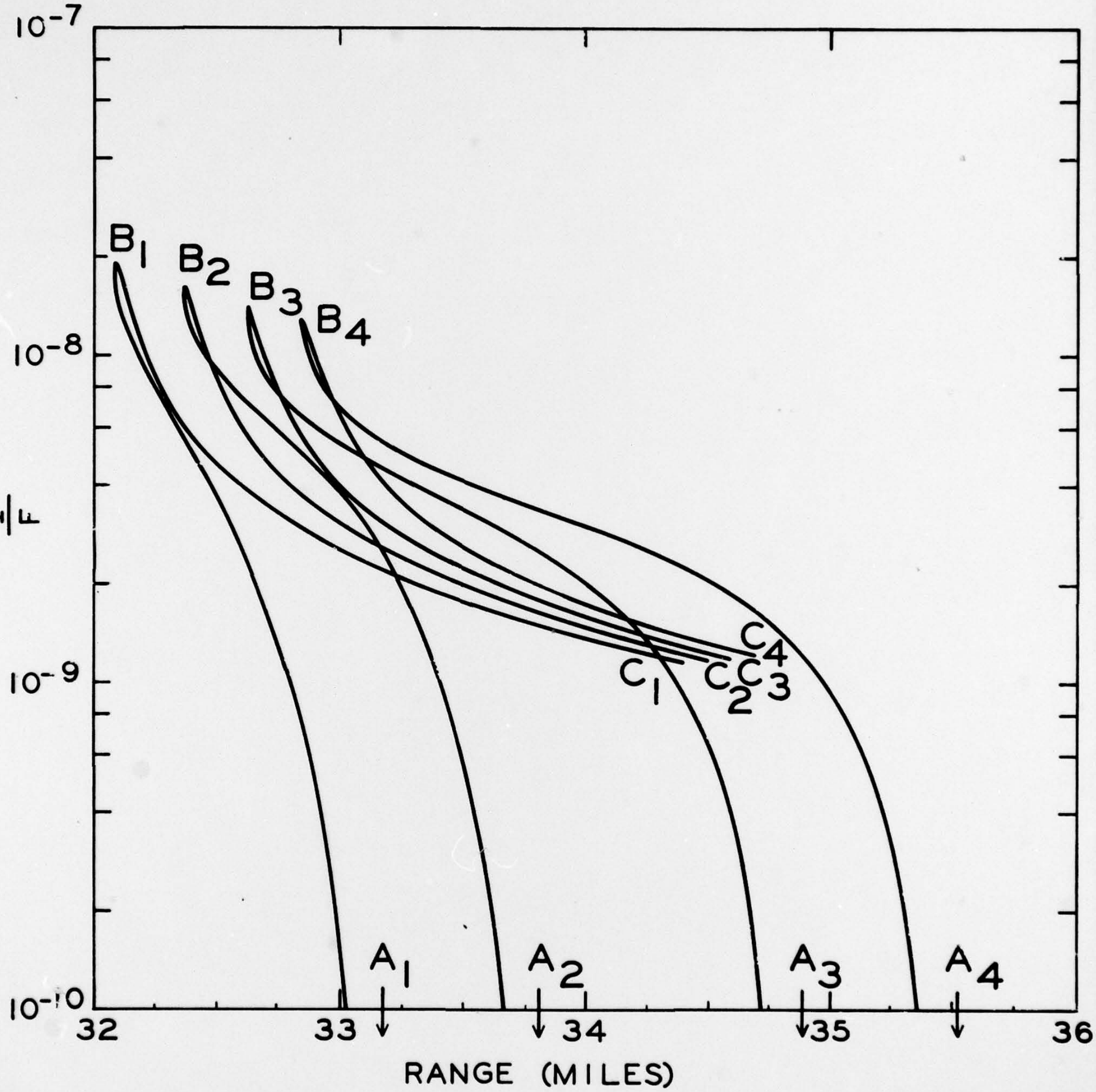

Fig. 2. Relative intensity of sound in the first LORAD zone along each of 8 paths from a 50-foot source to a 100-foot receiver. I/F is the ratio of intensity at the zone to that 1 yard from the source.

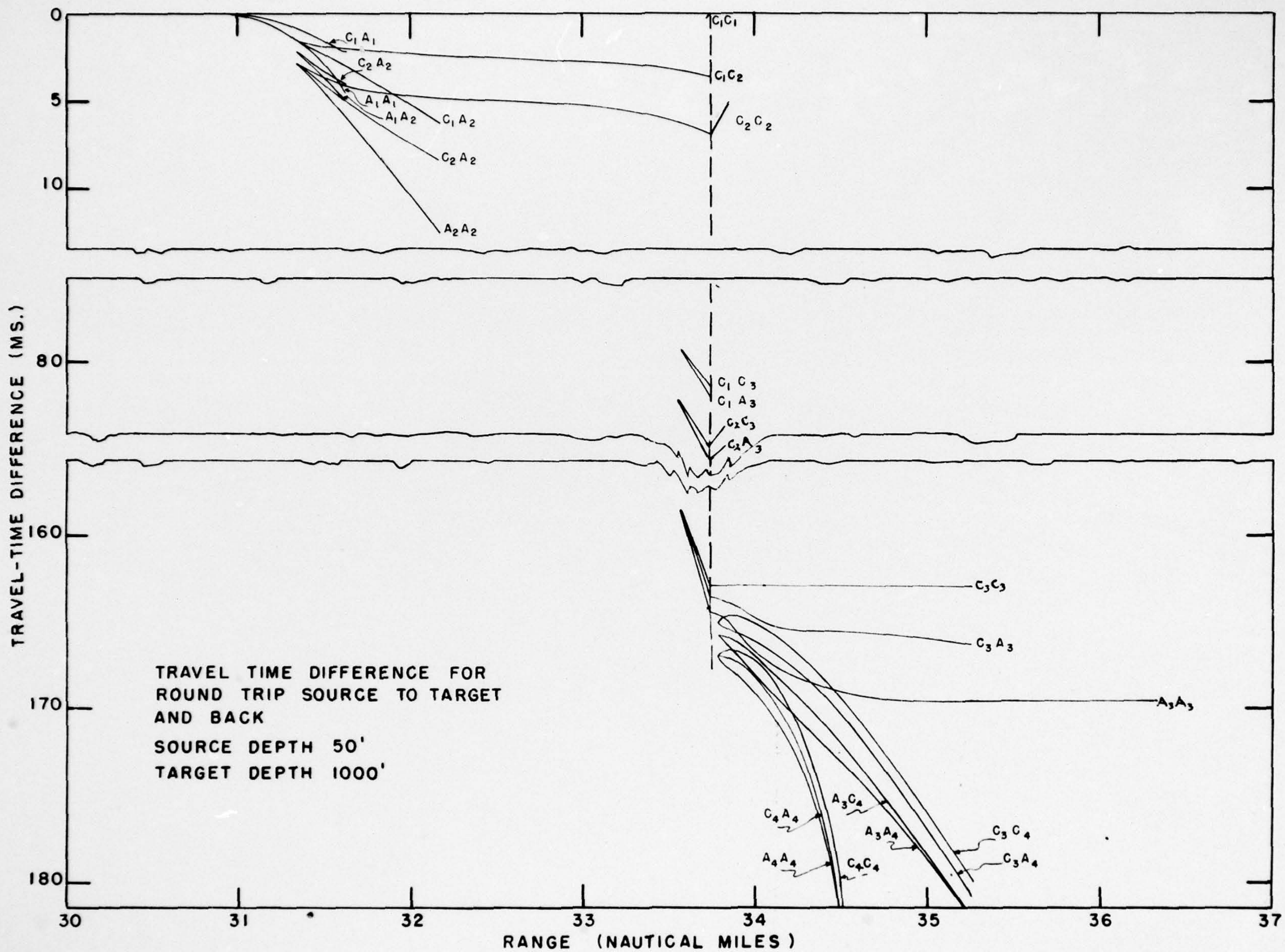

Fig. 3. Round-trip travel-time differences in milliseconds vs range in nautical miles for sound energy from a source 50-feet deep to and from a target 1000-feet deep in the first LORAD zone.

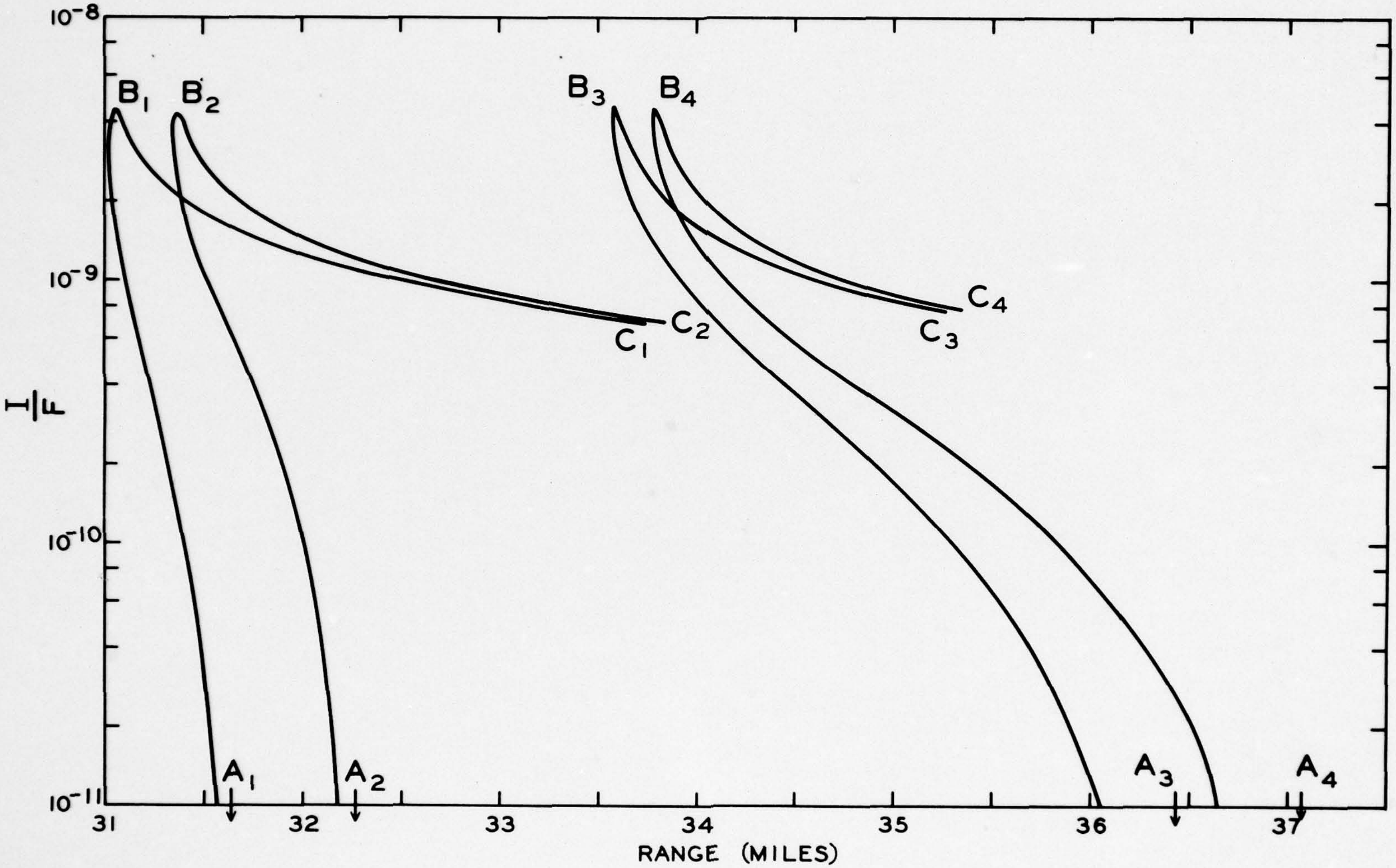

Fig. 4. Relative intensity of sound in the first LORAD zone along each of 8 paths from a 50-foot source to a 1000-foot receiver. I/F is the ratio of intensity at the zone to that 1 yard from the source.

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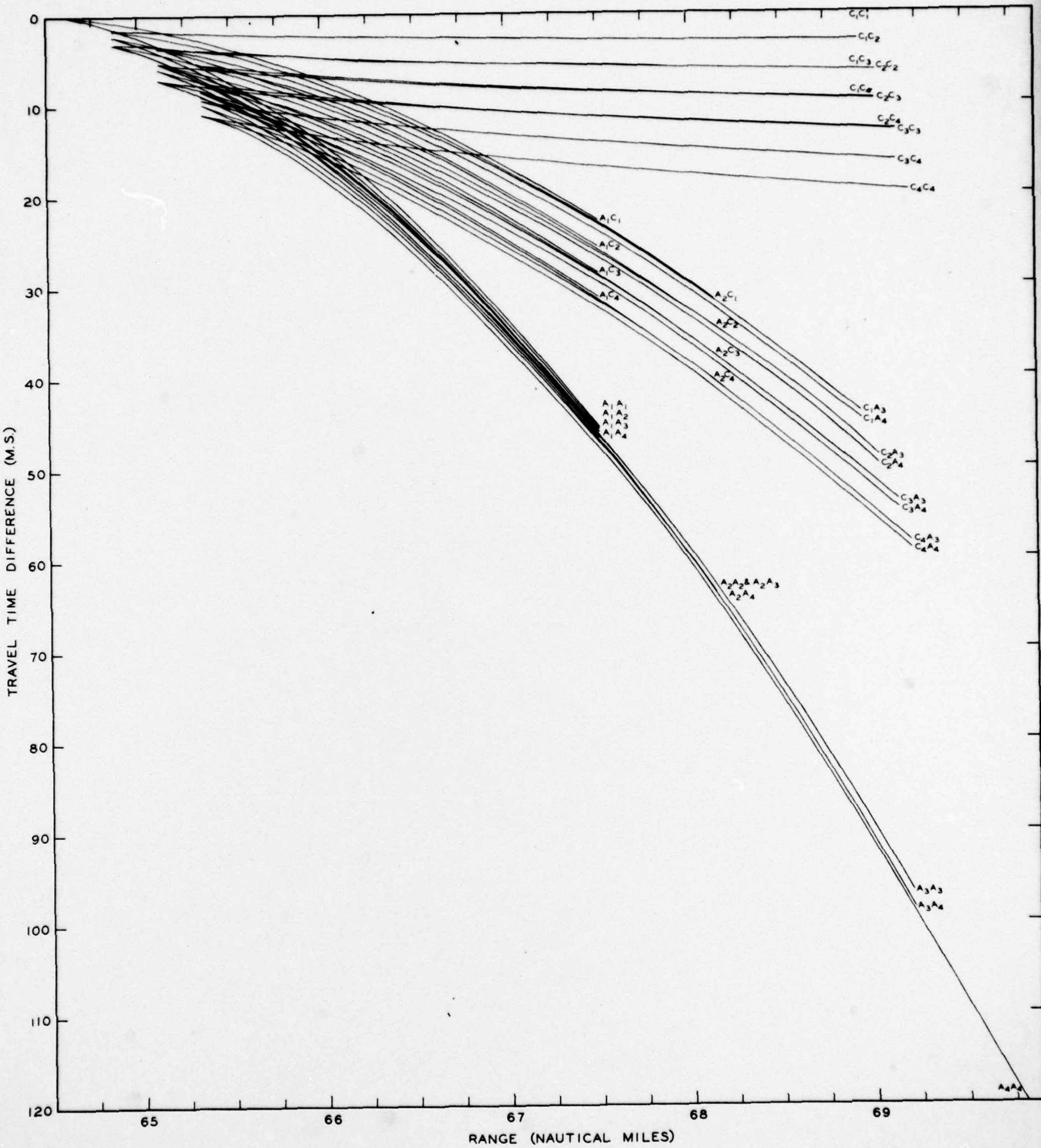

Fig. 5. Round-trip travel-time differences in milliseconds vs range in nautical miles for sound energy from a source 50 feet deep to and from a target 100 feet deep in the second LORAD zone.

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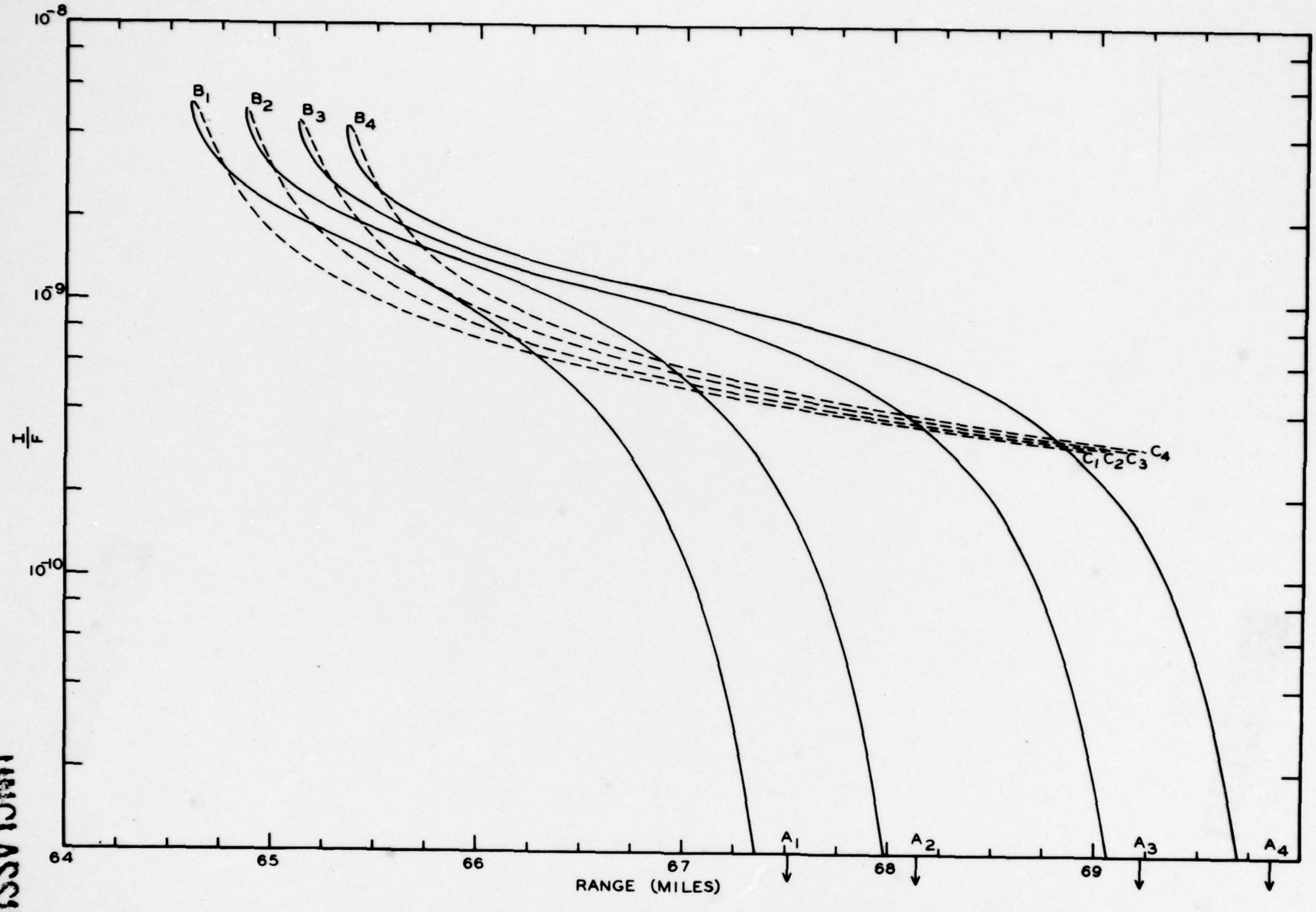

Fig. 6. Relative intensity of sound in the second LORAD zone along each of 8 paths from a 50-foot source to a 100-foot receiver. I/F is the ratio of intensity at the zone to that 1 yard from the source.

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